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BAY SPRINGS CANAL SURGE STUDY, TENNESSEE-TOMBIGBEE WATERWAY, MI--ETC(U)
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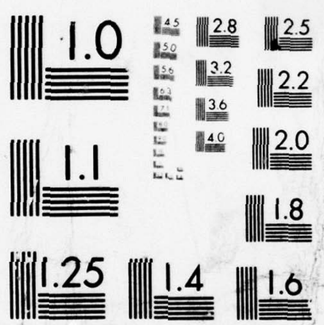


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TECHNICAL REPORT H-78-9

LEVEL II

(6) BAY SPRINGS CANAL SURGE STUDY, TENNESSEE-TOMBIGBEE WATERWAY, MISSISSIPPI AND ALABAMA,

Hydraulic Model Investigation.

by

(10) Charles H. Tate, Jr.

(12) 31p.

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180



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Nashville, Tennessee 37202

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|---|---|
| Bay Springs Canal | Navigation conditions |
| Hydraulic models | Surges |
| Locks (Waterways) | Tennessee-Tombigbee Waterway |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A 1:80-scale hydraulic model was used to study flow conditions in the canal downstream of the proposed Bay Springs Lock. The original design and plan of operation caused severe conditions in the canal and required modification (design 2) of the lock discharge system and lower approach geometry.

Based on the results of this study, the design 2 diffuser and lower approach with a 2-min emptying valve schedule should provide satisfactory navigation conditions downstream of the project. This design is expected to produce

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20. ABSTRACT (Continued).

a relatively slow upwelling of the water surface in the lower approach with a maximum height of 2.5 ft and to exert a force of less than 36 tons on a tow similar to that used in the study.

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## PREFACE

The hydraulic model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army (OCE), on 3 October 1974, at the request of the U. S. Army Engineer District, Nashville.

The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period October 1974 to July 1976. Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Structures Division, directed the investigation. The study was conducted by Mr. Charles H. Tate, Jr., Project Engineer, under the direct supervision of Mr. J. P. Bohan, former Chief of the Spillways and Channels Branch. Mr. Robert Bryant assisted in testing the model.

During the course of the study, meetings were held at WES to discuss the results of the surge model and related studies being conducted by the Hydraulics Laboratory. Corps of Engineers personnel representing OCE, Ohio River Division, South Atlantic Division, Nashville District (ORN), Mobile District, and WES attended these meetings. ORN correlated these results with design studies.

Directors of WES during the conduct of the study and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| feet | 0.3048 | metres |
| miles (U. S. statute) | 1.609344 | kilometres |
| feet per second | 0.3048 | metres per second |
| cubic feet | 0.02831685 | cubic metres |
| tons (force) | 8896.444 | newtons |
| degrees (angle) | 0.01745329 | radians |

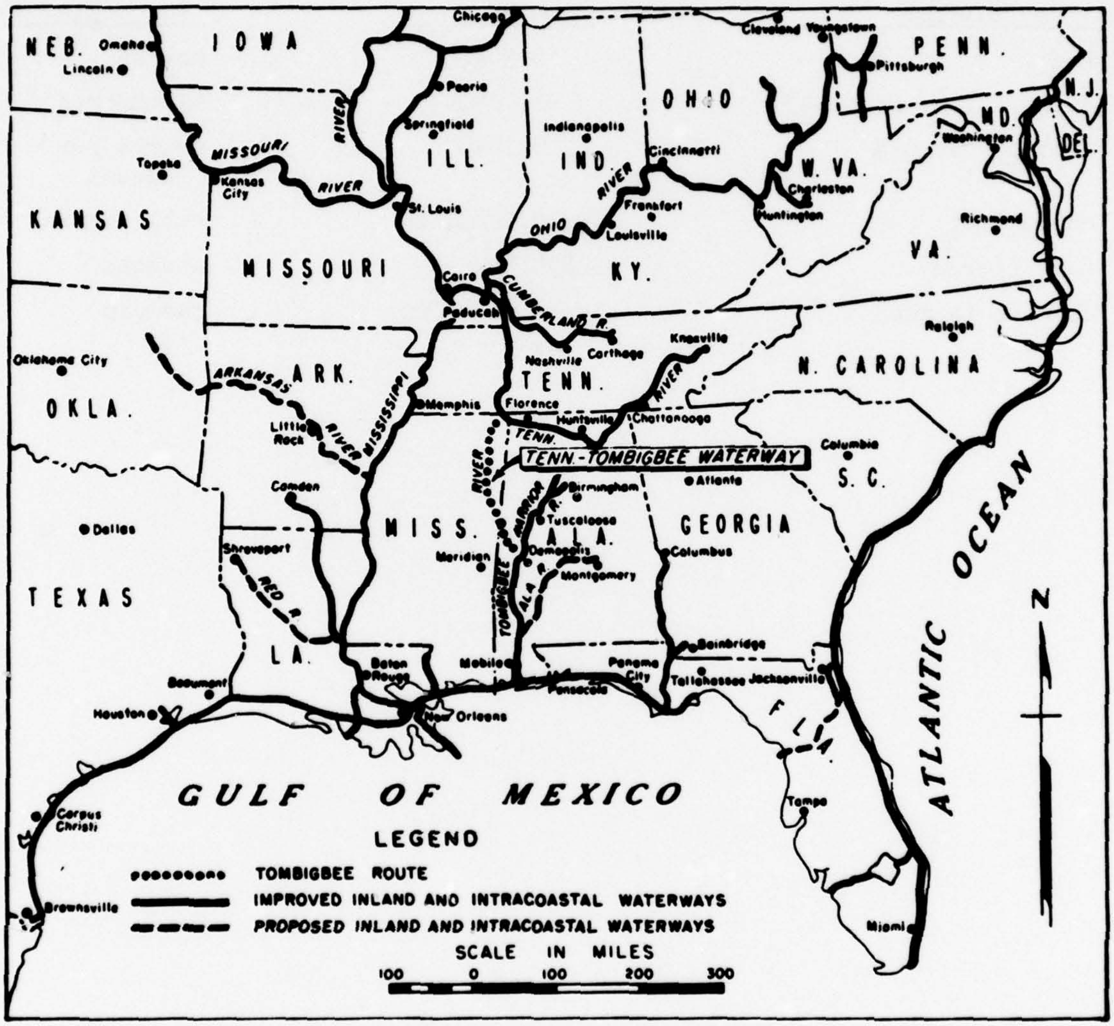


Figure 1. Location map

BAY SPRINGS CANAL SURGE STUDY, TENNESSEE-TOMBIGBEE WATERWAY

MISSISSIPPI AND ALABAMA

Hydraulic Model Investigation

# PART I: INTRODUCTION

## Project Overview

1. The Tennessee-Tombigbee Waterway will be a navigable waterway composed of natural rivers and streams and man-made canals, locks, and dams. The waterway, located in Alabama, Mississippi, and Tennessee (Figure 1), will extend upstream from Demopolis, Alabama (on the existing Black Warrior-Tombigbee Waterway 217 miles* above Mobile, Alabama), by way of the Tombigbee River to the east fork of the Tombigbee. The project then will extend up Mackeys Creek, through a deep cut in the Tennessee Valley Divide, to Pickwick Lake by way of Yellow Creek. The waterway joins the Tennessee River System near the common boundary of Mississippi, Alabama, and Tennessee (Figure 2).

2. The "Tenn-Tom" is divided into the River Section, Canal Section, and Divide Section as shown in Figure 2. The River and Canal Sections extend from Demopolis, Alabama, to the Bay Springs Lock and Dam in Mackeys Creek. These two sections are 213 miles long and will have nine conventional locks to overcome a difference in elevation** of 257 ft. The Divide Section consists of an 84-ft-lift lock at the Bay Springs Dam and a 27-mile-long canal to be cut through the Tennessee Valley Divide into the Yellow Creek Embayment of Pickwick Lake.

3. The main justification of the Tennessee-Tombigbee Waterway is the reduced transportation costs for moving barges from the Gulf of Mexico to the Tennessee River System. Instead of navigating the

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is given on page 3.

** All elevations (el) cited herein are in feet referred to mean sea level.

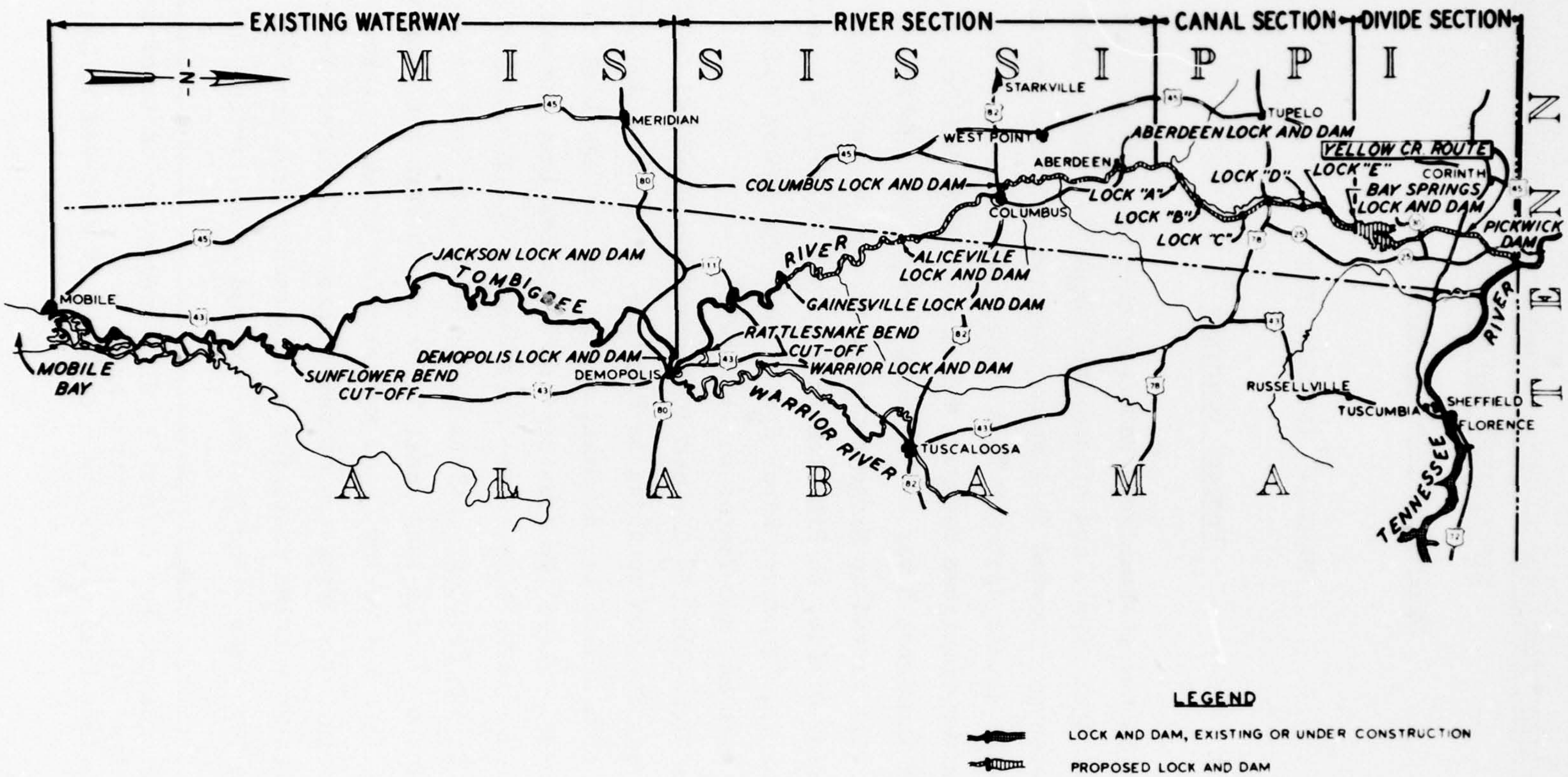



Figure 2. Vicinity map

Mississippi and Ohio Rivers to reach the Tennessee River System, tows can navigate directly from Mobile, Alabama. Although the largest part of the economic justification was the decreased transportation cost, recreational benefits, fish and wildlife enhancement, and area development were also included.

## Project Description

4. Bay Springs Lock and Dam will be located in northeast Mississippi on the Tennessee-Tombigbee Waterway, west of Belmont, Mississippi, and one-half mile south of Mississippi Highway 4 on Mackeys Creek.

5. Bay Springs Lake is designed to have a maximum pool elevation of 422; however, the maximum normal pool will be el 414 (summer condition). The 110-ft-wide by 670-ft-long (pintle to pintle) lock will be located at the left end of the dam and will provide an 84-ft lift to el 414 for tows up to 600 ft long. Filling and emptying of the lock will normally occur through two intakes, two culverts, a longitudinal floor culvert system, and two diffusers (Plate 1). Reverse tainter valves located in the culverts will control flow and the rate of filling and emptying of the lock chamber. Discharges from the lock will pass through the culverts and diffusers into the downstream approach and canal (Plate 2).

6. The canal will have a base width of 300 ft and a depth of 13 ft with the normal water surface (el 330) that will be provided by Lock and Dam E which will be located 5.2 miles downstream of Bay Springs Lock and Dam. The canal will be excavated in rock with side slopes of 4V on 1H for a distance of approximately 1 mile downstream of Bay Springs Lock and Dam and will enter the headwaters of pool E about 2.5 miles downstream of Bay Springs Lock and Dam. Although the plan and design of the Bay Springs Lock filling and emptying system were conducted in accordance with the latest criteria and guidance, there was concern relative to flow conditions in the immediate lower approach and the effect on navigation due to emptying 6.19 million cu ft of water from the lock chamber in a relatively short time. Therefore, a physical

model investigation was conducted to define the surge to be expected in the relatively narrow and shallow canal due to emptying the navigation lock.

## Purpose and Scope of the Study

7. The purpose and scope of the canal surge study were originally to evaluate the hydraulic performance of the proposed diffuser design and operations scheme and to determine the effect of the releases from Bay Springs Lock on surge conditions and navigation in the relatively small canal downstream of the lock. Based on the results of these initial tests, the scope was later expanded to include development of a diffuser design and operation scheme that would provide satisfactory navigation conditions downstream of the lock.

8. A physical hydraulic model was used to study the diffuser system and lower approach area from the downstream miter gates of the lock to a point 3500 ft downstream in the canal. Lock discharge hydrographs for various valve schedules were imposed on several designs to determine the most favorable design and operation scheme.

## PART II: THE MODEL

9. A 1:80-scale undistorted model was designed using the accepted equations of hydraulic similitude based on Froudian criteria. The mathematical relations between the dimensions and hydraulic quantities of the model and prototype are expressed in terms of the model scale or length ratio, $L_r$ , and are presented in the following tabulation:

| Dimension | Ratio | Scale Relation |
|---|---|---|
| Length | $L_r$ | 1:80 |
| Area | $A_r = L_r^2$ | 1:6,400 |
| Velocity | $V_r = L_r^{1/2}$ | 1:8.944 |
| Discharge | $Q_r = L_r^{5/2}$ | 1:57,234 |
| Time | $T_r = L_r^{1/2}$ | 1:8.944 |
| Force | $F_r = L_r^3$ | 1:512,000 |

10. The model was constructed of clear acrylic plastic and reproduced a 3500-ft length of the lower approach and canal downstream of the lock (Figure 3). The model was automated in order to consistently reproduce the rapidly varying flow entering the canal from the lock. Flows of this nature were expected to create rapid fluctuations of the water surface in the canal. Consequently, the data collection system was automated to obtain continuous recordings of the water surface and forces on moored tows (Figure 4). The original design approach walls and diffusers were reproduced schematically in their correct locations (Figure 3). Flow was provided and controlled by means of two variable-speed, programmable, positive displacement pumps and four actuated butterfly valves. The model was later modified to provide flow from a head tank and actuated gate that reproduced the lock volume and head (Figure 5). The programmable, variable-speed, actuated gate on the head tank was used to impose the desired lock discharge hydrograph on the model.

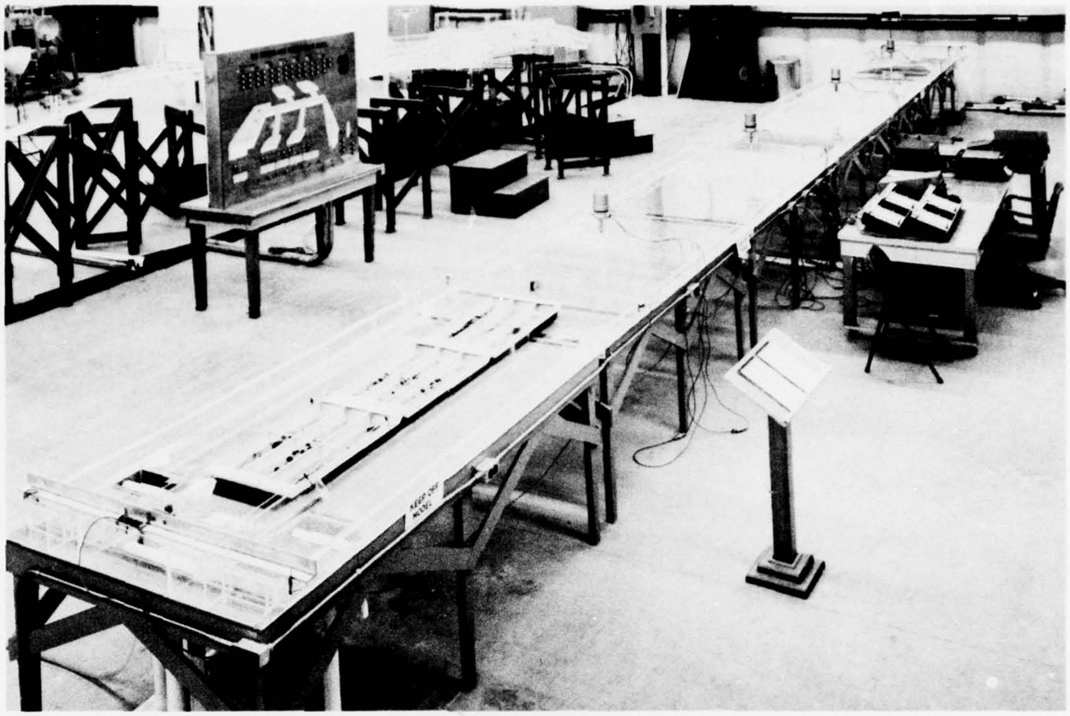
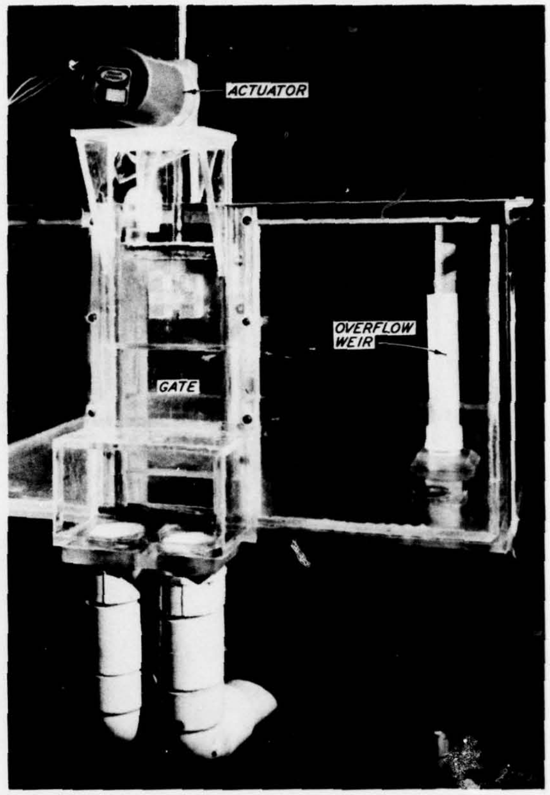


Figure 3. Model of the original design with model tow located between approach walls

Figure 4. Instrumentation for measuring water surfaces and forces on moored tows

Figure 5. Head tank




11. Contacting water-surface detectors of a capacitance type (Figure 6) were used in conjunction with X-Y plotters (Figure 4) to produce a continuous record of the water-surface elevation versus time for each test. Four of these detectors were used and mounted in a manner that allowed them to be moved to any point in the model.

12. A tow consisting of nine barges loaded to a 9-ft draft (prototype) was used in obtaining the total force on a moored tow. Total force in the upstream and downstream directions was measured by WES-built (U. S. Army Engineer Waterways Experiment Station) load cells and recorded on a strip chart recorder. The barges and a remote-controlled motorized towboat (Figure 7) were used to study the effects of the surge* on tows moving upstream (approaching the lock). These

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* For this study "surge" shall refer to the water-surface fluctuations induced by emptying the navigation lock.

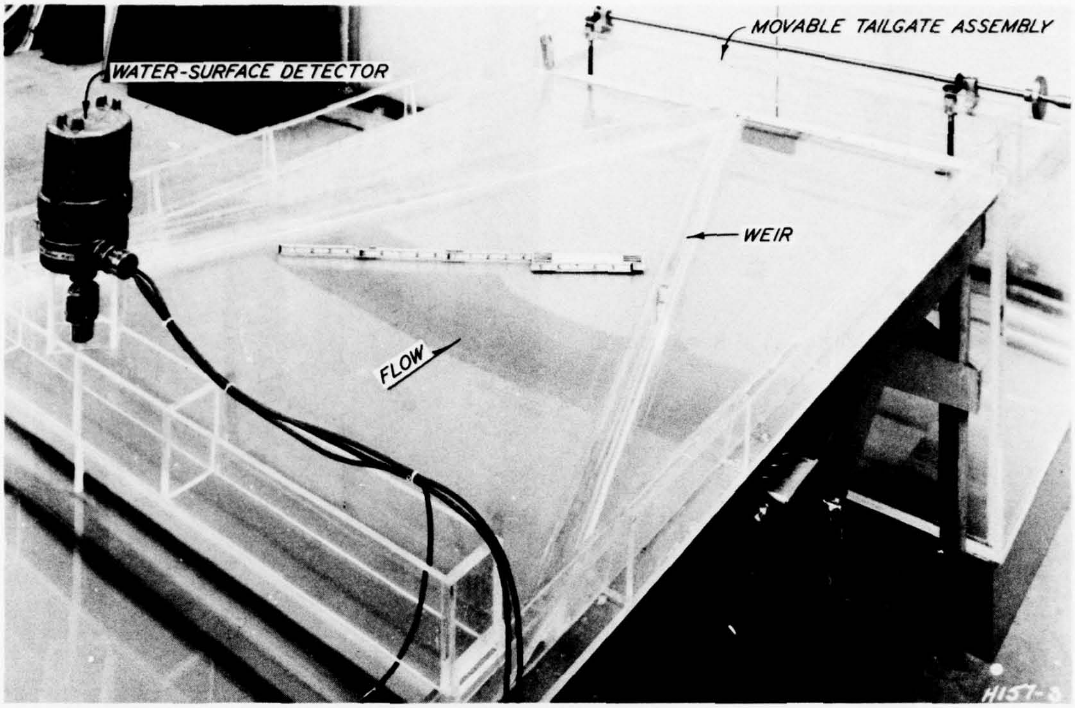


Figure 6. Antireflection weir

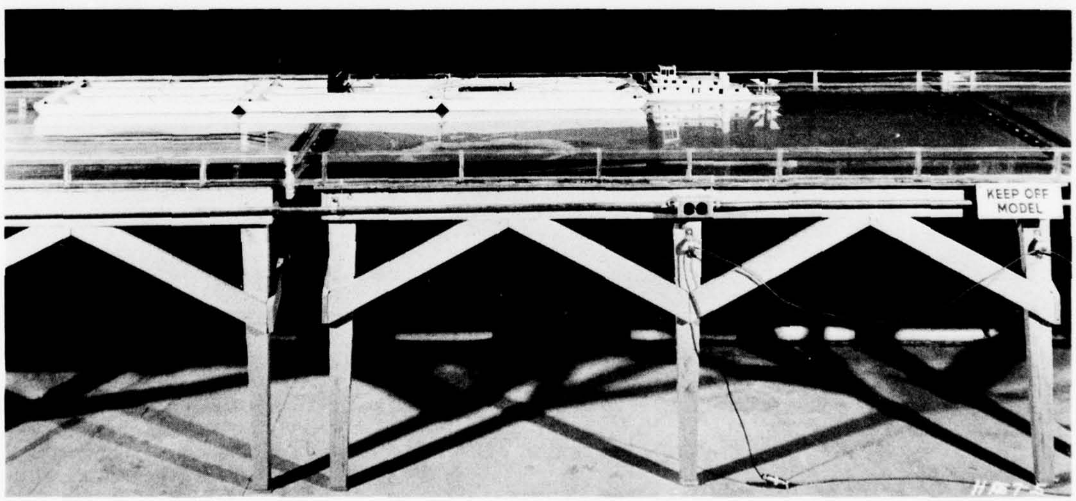


Figure 7. Radio-controlled towboat with barges

effects were evaluated by means of visual observations, and motion picture and time-lapse photography documentation.

13. The model was originally constructed with a stationary, vertical tailgate to maintain the water surface in the canal at el 330; however, preliminary testing disclosed the need to modify this design. As the leading edge of the surge impinged on the tailgate, a reflected wave propagated upstream and obscured the remainder of the inital surge. Several types of sloping and porous breakwaters and tailgate combinations were tested without success in an effort to dissipate the reflected wave. The successful effort used the energy to pass the surge through the model and consisted of a "V" shaped stationary tailgate or weir with a 45-degree sloping upstream face and a 40-degree apex angle (Figure 6). This weir repeatedly reflected the surge downstream and out of the model with no observable upstream reflections.

## PART III: TESTS AND RESULTS

### Original Design

14. All data herein are expressed in prototype terms. "Upstream" indicates direction toward Bay Springs Lake, and "downstream" indicates direction toward pool "E." "Left" and "right" indicate directions when looking downstream. Distances are measured from the downstream miter gate pintles (sta 00+00).

15. Operations proposed with the original design diffusers and lower approach configuration (Plate 3) specified a 1-min opening time (valve speed) for the emptying valves and a computed lock emptying time of 11.9 min. Water surfaces as a function of time were recorded in the canal at various locations without the presence of a tow in the model (Plate 4). This operation produced a 1.9-ft-high translatory wave with a steepening leading face which when approximately 2000 ft downstream transformed into an undular wave with crests increasing to 2.6 ft above normal pool at the downstream end of the model. The surge was similar in appearance to a classical bore. The rate of rise of the water surface due to the surge passing a given point increased from 0.11 fps at sta 10+00 to 0.49 fps at sta 34+00. Forces resulting from the discharge hydrographs on a tow moored at four different locations are shown in Plate 5 and indicate severe conditions relative to navigation. The maximum force of 170 tons was observed with the barges moored 150 ft downstream. This force was caused in part by the buildup of water ahead of the barges or tow moored between the approach walls and involved a 5-ton-per-second (tps) rate of loading. A minimum peak force of 70 tons was observed on tows located between 400 and 1100 ft downstream. With tows positioned at distances greater than 1100 ft, the peak force increased with distance downstream. At sta 18+60, the rate of loading had increased to 29 tps.

16. Observations from tests using a motorized, radio-controlled towboat indicated that a tow moving upstream at approach speeds of 4 to 6 fps would be transported 60 to 120 ft downstream by the lock release

even when increased power was applied by the towboat during the surge.

17. After installing the head tank and actuated gate in the inflow system of the model, tests were run to determine the effect of slowing the emptying valve opening speed. Valve opening times of 2, 4, and 8 min were tested and these slower valve opening times resulted in a definite reduction of surge heights and maximum forces exerted on moored tows. The 2-min valve schedule reduced the forces to approximately one third of those produced by the original 1-min valve schedule at all locations. Forces with 4- and 8-min valve schedules were only slightly lower than those observed with the 2-min valve schedule. The longer valve times lengthened the lockage time considerably.

18. Analysis of the data obtained with the original design yielded three significant conclusions: (a) the undular wave did not form in the model with valve opening times greater than 1 min, (b) the slope of the water surface rather than the surge height was a good indicator of the forces to be exerted on a tow, and (c) the slope of the water surface was a function of the speed at which the emptying valve was opened.

## Design 2 Diffuser and Lower Approach

19. Since performance with the original design diffuser and with the 1-min valve schedule was not considered to be satisfactory, a new design was formulated and tested. The type 2 design diffuser and lower approach included realigning the lock and canal to place the lock guide wall on the right bank of the canal (Plate 6, Figure 8). This permits tows to use the full width of the canal when maneuvering to enter the lock. Additionally, the type 2 design diffuser and lower approach provided for a uniform discharge across the width of the canal.

20. The design 2 diffuser and lower approach was tested with 1- and 2-min valve schedules imposing the same release hydrographs as with the original design. Results of these tests indicated that design 2 was a more efficient energy dissipater. For a 1-min valve, the maximum water surface of the surge was slightly higher near the lock

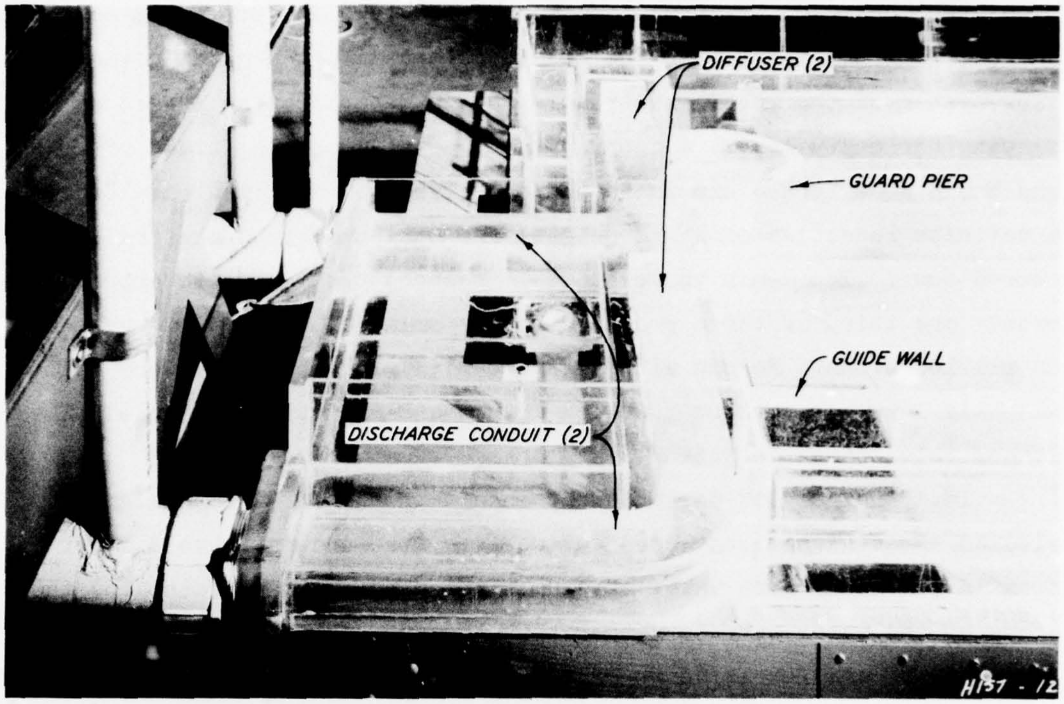


Figure 8. Design 2 diffuser system and lower approach

than with the original design, but the surge height decreased as the surge progressed downstream. Maximum forces of approximately 40 tons were measured at all points with the 1-min valve operation. Tests with the motorized tow indicated that a tow would be capable of maintaining headway through the surge. Using a 2-min valve, the maximum water surface near the lock was the same elevation as that with the original design and a 1-min valve; and again, the maximum surge height decreased as the surge progressed downstream. Maximum forces on the tow at any point were reduced to approximately 20 tons. These results and those of a 1:25-scale model study* of the filling and emptying system indicated that a 2-min emptying valve schedule should be recommended for prototype operations.

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* J. H. Ables, Jr., "Filling and Emptying System for Bay Springs Lock, Tennessee-Tombigbee Waterway; Hydraulic Model Investigation" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

## Expected Prototype Conditions

21. Thus far in the study, the lock release hydrographs imposed on the model were theoretical as computed by personnel in the U. S. Army Engineer District, Nashville. The 1:25-scale model of the filling and emptying system was used to determine the actual lock chamber stage versus time relation with the 2-min emptying valve schedule. Studies conducted by WES concerning the relation of filling and emptying times between model and prototype longitudinal floor culvert systems indicate that the prototype will empty about 18 percent faster than the model. Accordingly, the stage-time relation generated by the lock model was adjusted and tested in the surge facility. Results of these tests are shown in Plates 4 and 5 and labeled as "Expected Prototype Surge." These tests indicate the conditions that are expected to occur in the canal with the recommended design and a 2-min emptying valve schedule. The maximum rate of rise of the water surface was 0.06 fps with a maximum surge height 2.5 ft above normal pool. Forces on tows positioned anywhere within the limits simulated by the model did not exceed 36 tons and maintained a uniform rate of loading of approximately 1 tps. These values are somewhat greater than those previously observed for design 2 with a theoretically computed 2-min emptying valve hydrograph. This is to be expected due to the shorter emptying time (Plate 7) anticipated in the prototype lock.

## Additional Designs

22. Several modifications to design 2 were tested in an attempt to further improve performance. These designs used the basic layout of design 2 with various diffuser pit and approach floor modifications. Widening the top of the diffuser pit was not as effective in energy dissipation as design 2. Several lower approach floor elevations were tested, but they would not improve flow conditions in the canal.

## PART IV: CONCLUSIONS

23. The original design and plan of operation caused severe conditions in the canal and required modification (design 2) of the lock discharge system and lower approach geometry.

24. Based on the results of this study, the design 2 diffuser and lower approach with a 2-min emptying valve schedule should provide satisfactory navigation conditions downstream of the project. This design is expected to produce a relatively slow upwelling of the water surface in the lower approach with a maximum height of 2.5 ft and exert a force of less than 36 tons on a tow similar to that used in the study.

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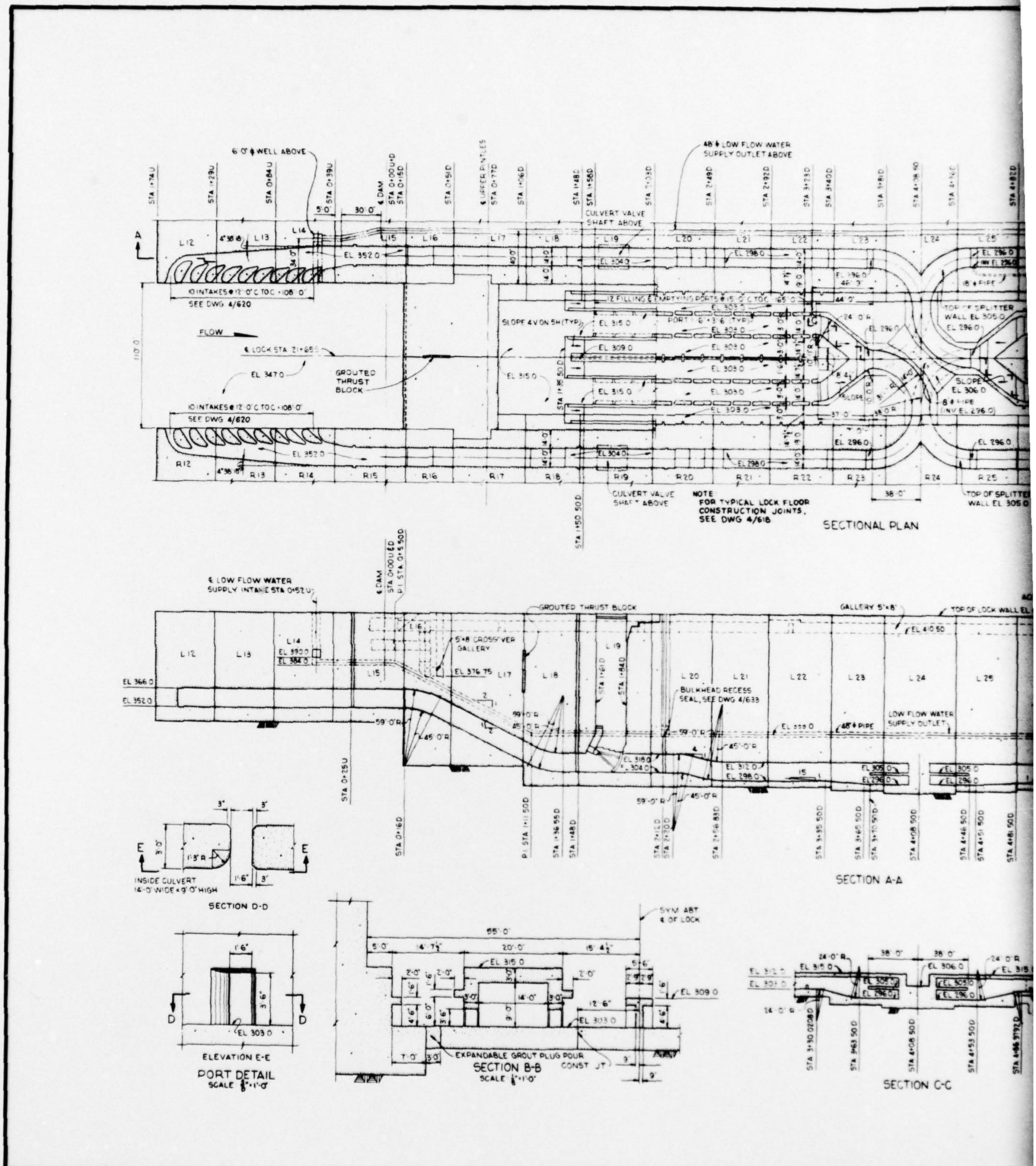
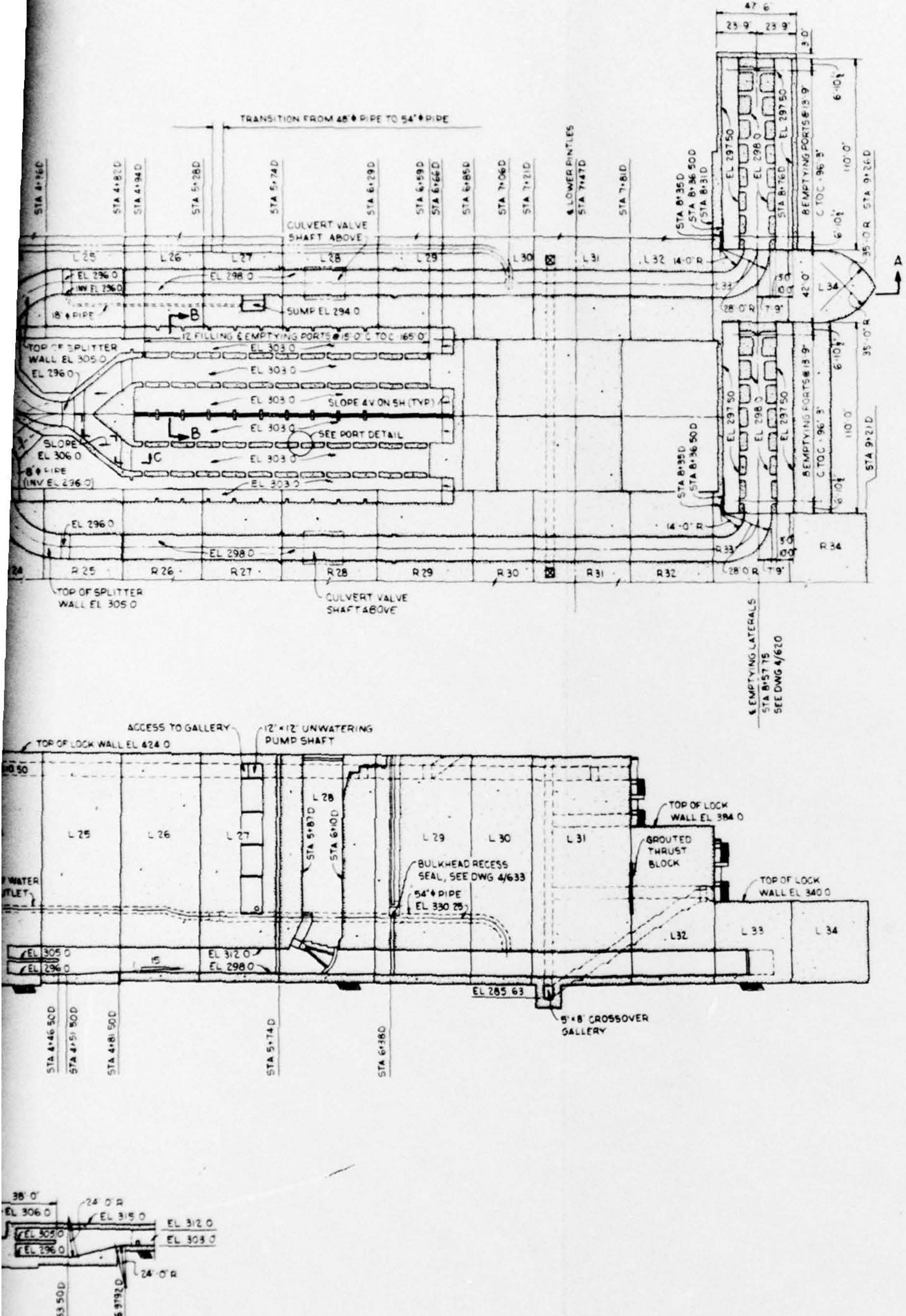
Wilhelms, S. C., "Bay Springs Lake Water-Quality Study; Hydraulic Model Investigation," Technical Report H-76-7, May 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.



SECTIONAL PLAN
SECTION A-A
SECTION D-D
ELEVATION E-E
PORT DETAIL
SCALE 3/8"=1'-0"
SECTION B-B
SCALE 1/8"=1'-0"
SECTION C-C
FLOW
GROUTED THRUST BLOCK
10 INTAKES @ 12'-0" C TO C = 108'-0"
SEE DWG 4/620
12 FILLING & EMPTYING PORTS @ 15'-0" C TO C = 165'-0"
CULVERT VALVE SHAFT ABOVE
48" ϕ LOW FLOW WATER SUPPLY OUTLET ABOVE
6'-0" ϕ WELL ABOVE
NOTE
FOR TYPICAL LOCK FLOOR CONSTRUCTION JOINTS, SEE DWG 4/618
TOP OF SPLITTER WALL EL 305.0
INSIDE CULVERT 14'-0" WIDE x 9'-0" HIGH
EXPANDABLE GROUT PLUG POUR
CONST JT
SYM ABT ℄ OF LOCK
GALLERY 5'x8'
TOP OF LOCK WALL EL
BULKHEAD RECESS SEAL, SEE DWG 4/633
LOW FLOW WATER SUPPLY OUTLET
5'x8' CROSSOVER GALLERY



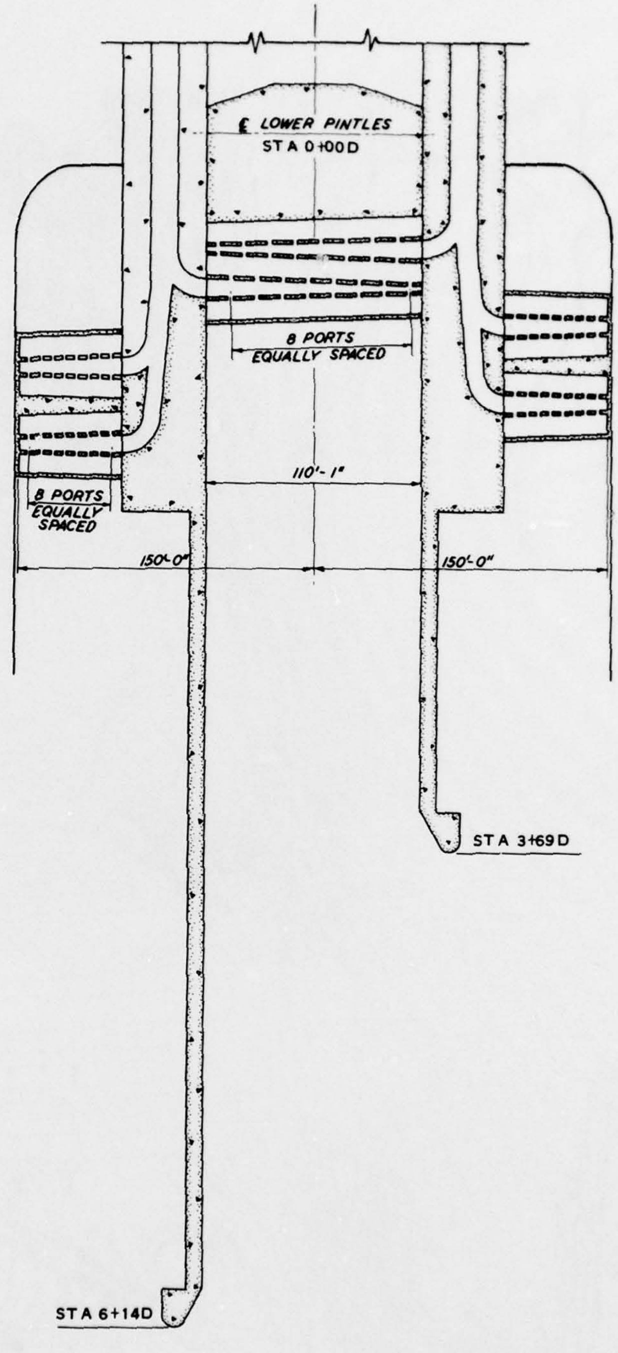
FILLING AND EMPTYING SYSTEM WITH DESIGN 2 DIFFUSER SYSTEM

SECTIONAL PLAN AND ELEVATION

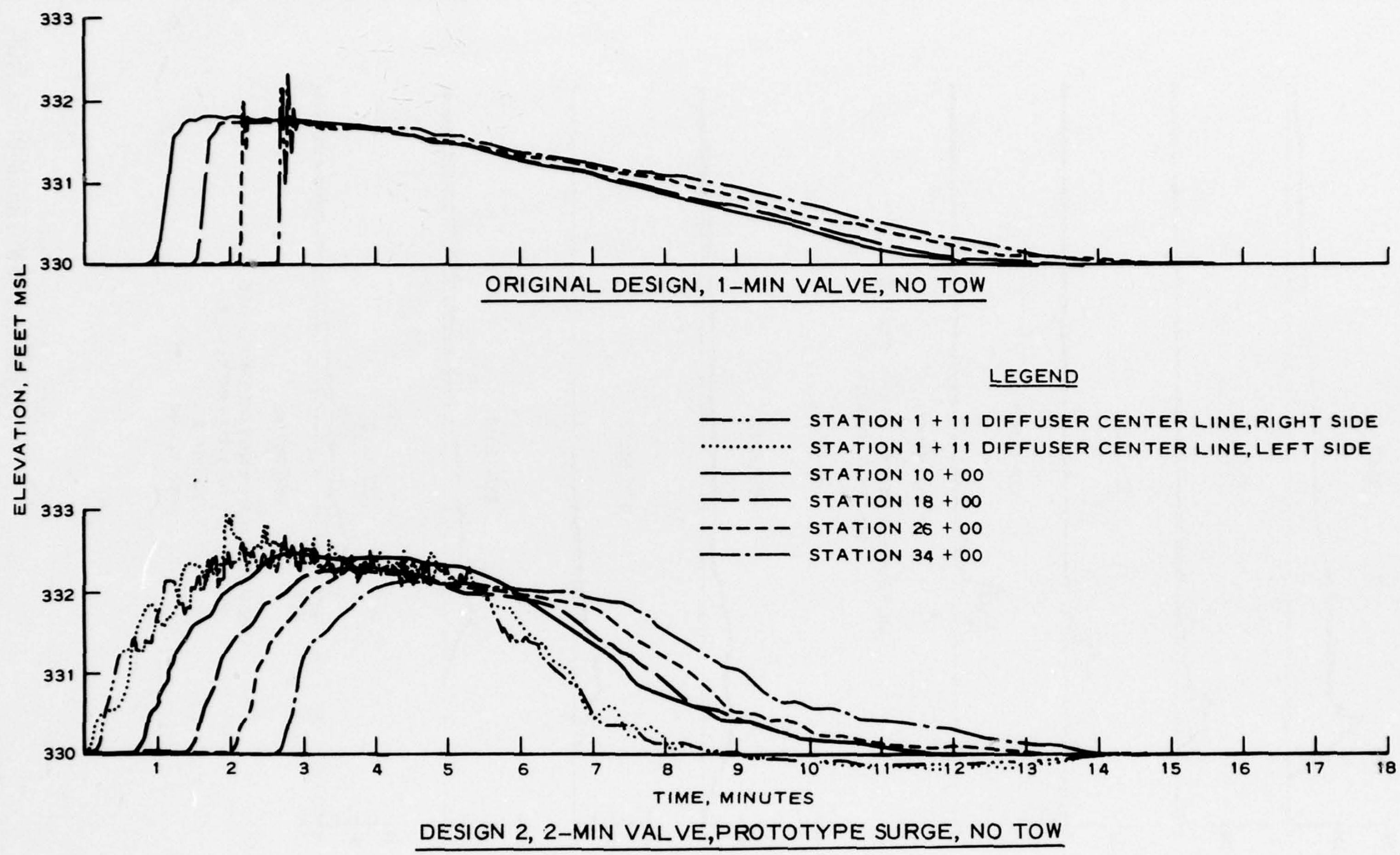
PLATE 1

2

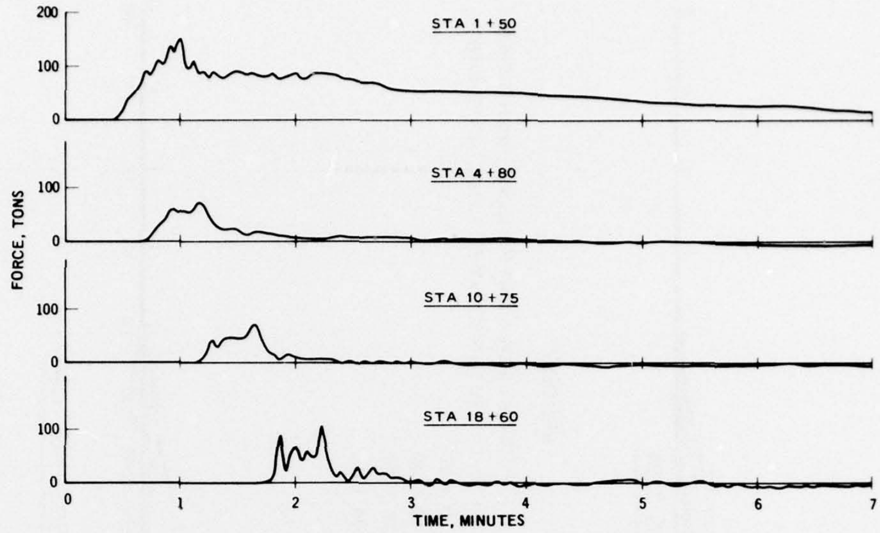

AREA PLAN FOR
DESIGN 2 SHOWING
LOCK-CANAL ALIGNMENT




ORIGINAL DESIGN
DIFFUSERS AND LOWER APPROACH

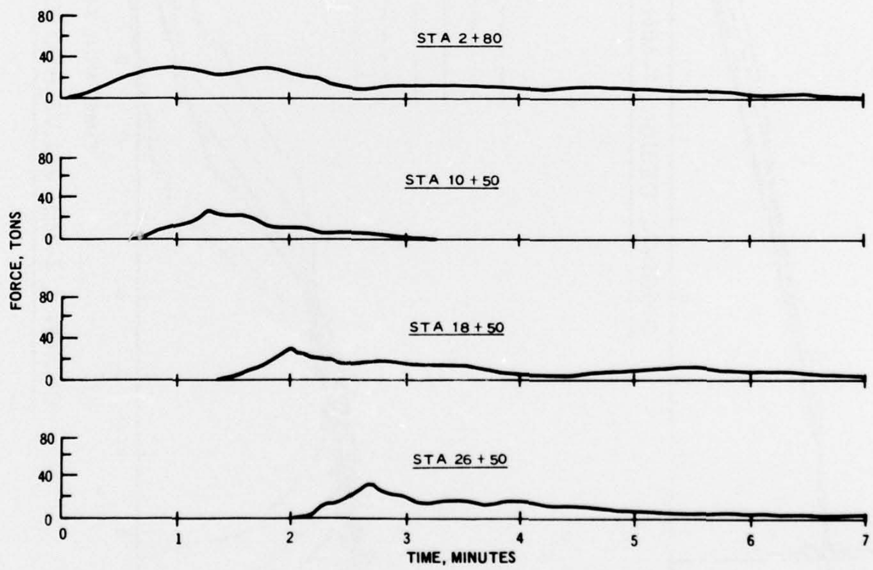



WATER-SURFACE PROFILES



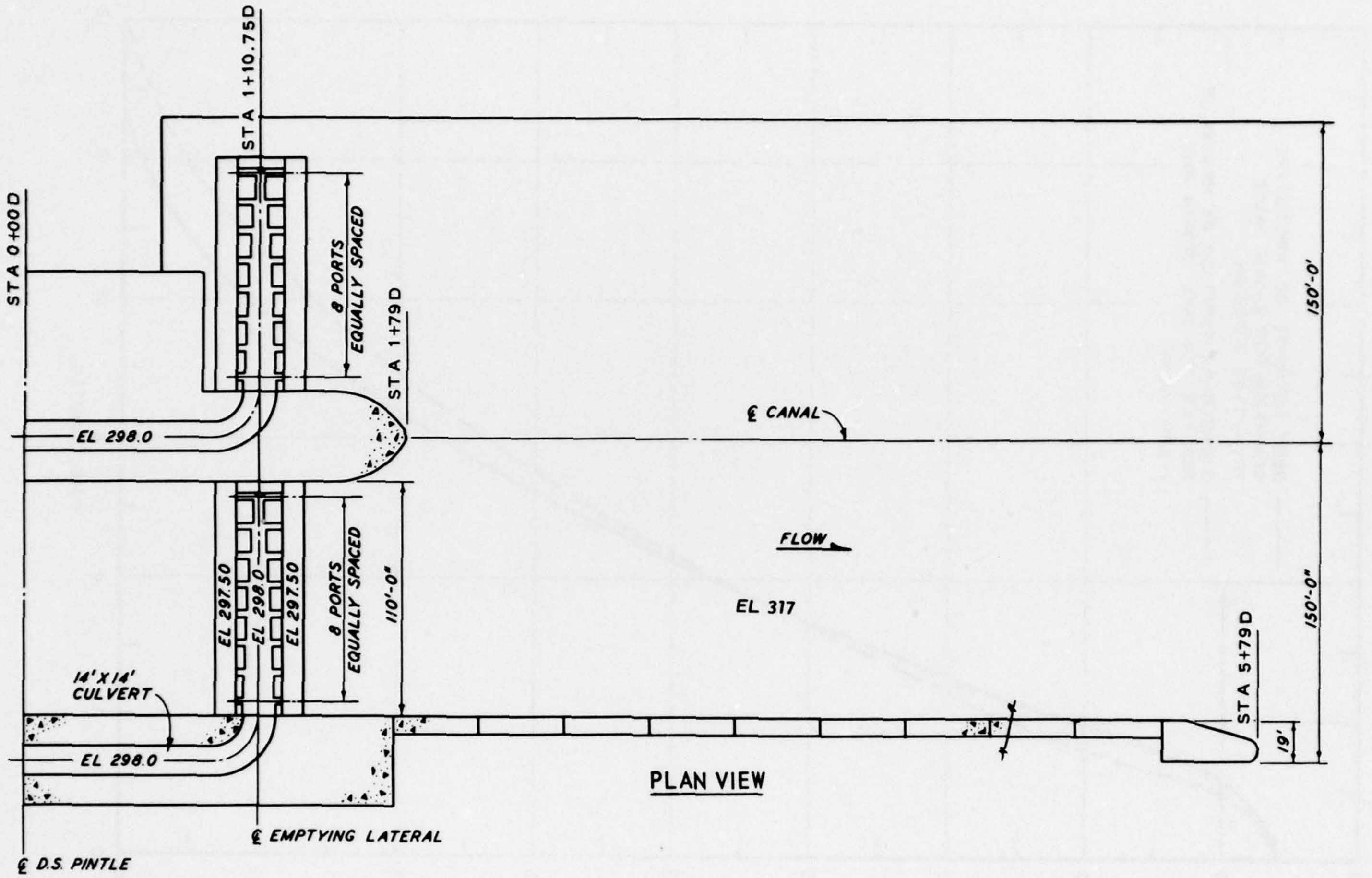

MEASURED DOWNSTREAM FORCE
ORIGINAL DESIGN

1-MIN VALVE

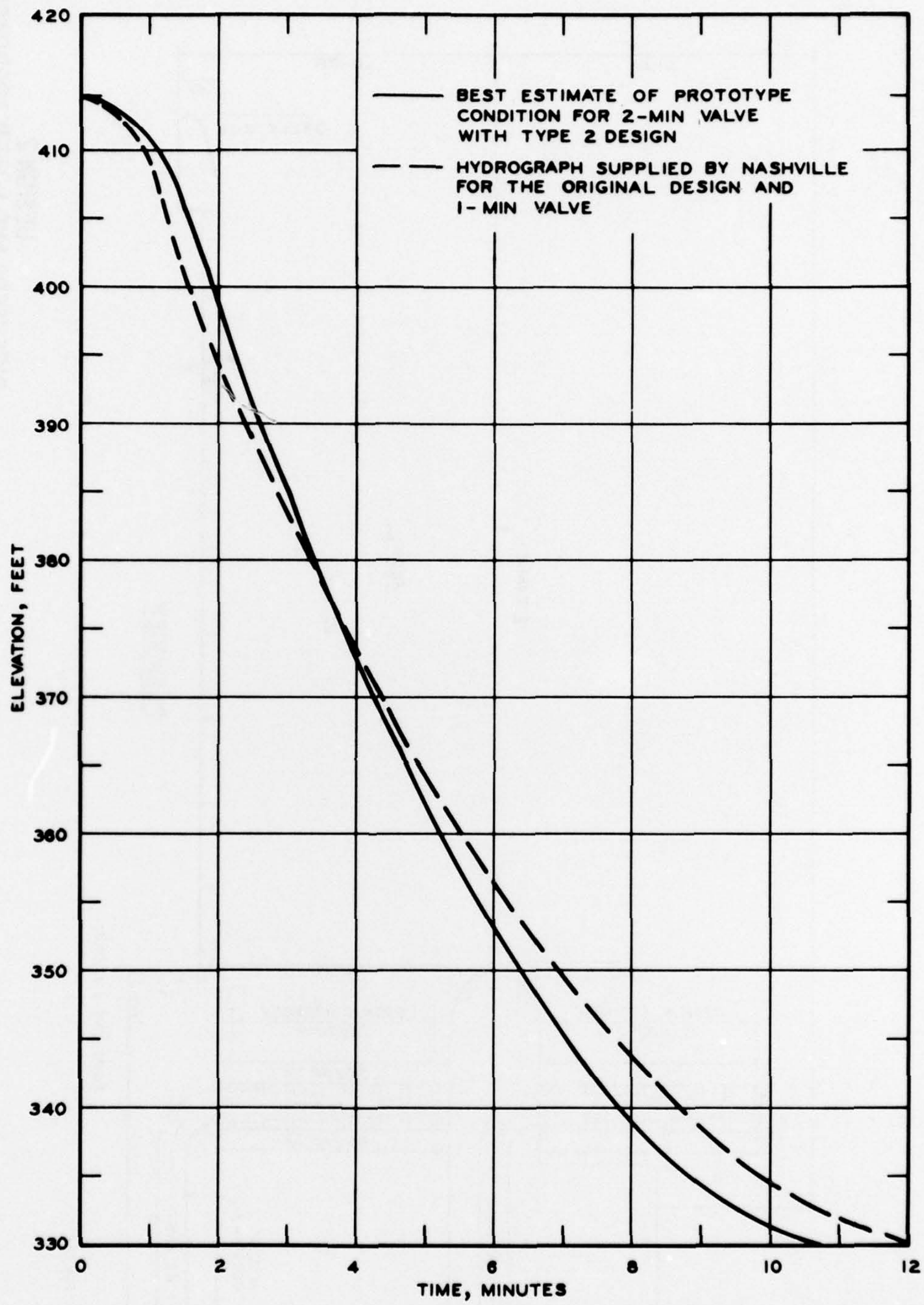



MEASURED DOWNSTREAM FORCE
EXPECTED PROTOTYPE SURGE
DESIGN 2
2-MIN VALVE

FORCE IN DOWNSTREAM DIRECTION




DESIGN 2
DIFFUSERS AND LOWER APPROACH




LOCK STAGE VERSUS TIME

PLATE 7

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.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19 p., 7 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-78-9)

Prepared for U. S. Army Engineer District, Nashville, Nashville, Tennessee.

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1. Bay Springs Canal. 2. Hydraulic models. 3. Locks (Waterways). 4. Navigation conditions. 5. Surges. 6. Tennessee-Tombigbee Waterway. I. United States. Army. Corps of Engineers. Nashville District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-78-9.

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